Designing and Building a Pipe Marimba

An Honors Thesis (MUMET 495)

By

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Abstract

In the modern world, musical expression is becoming a technological process as much as an emotive work. Yet for many, music creation remains a tactile, physical experience. Before the experience of making music, though, is the process of building such concrete instruments. Employing certain acoustical principles, I have designed and built an instrument that provides this tangible experience. These plans are available for future instrument builders to use and improve. This document describes why and how I built this instrument, as well as the functional acoustical formula that inspired this design.

Acknowledgements

I would like to thank Dr. Pounds for his advice and assistance throughout the course of this project. It has been enjoyable to learn from such a knowledgeable and experienced professor and music engineer.

I would also like to thank Nathan Hack, Kurtis Moss, Karl Rauchenstein, and David DelaGardelle for allowing me to use their space and time to build this instrument. I had a great time testing the instrument with my friends all as well.

Vision Statement

I have had the desire for years to build my own musical instrument. I came to Ball State University to study music technology in order to gain knowledge on the periphery of a typical musician's mind. I prefer to tune the acoustics of a room and then fine-tune the equalization of the soundboard rather than being the musician who performs onstage. For this project, I devoted myself to create a platform from which a musician could create music, specifically a pipe marimba. A pipe marimba is a percussion instrument that produces sound through a vibrating air column. Additionally, I wanted to design a set of blueprints and instructional videos so that others could follow, or even improve upon, my design.

Following the "open source" model, this project is designed in a way that others are able to take the general principles and source files and revise and edit them to fit each person's own design requirements without the fear of "stealing" or infringing upon the creator's rights. For added accessibility, I tried to limit the cost of building materials so the project would not be cost-prohibitive. In the end, a pipe marimba seemed the most feasible to fit within the requirements that I had placed upon myself.

In order to achieve this task, I had to do the entire project in multiple steps. First, I had to actually design and build an instrument. This, in some ways, was only the beginning of the project. It took some basic engineering to draw a blueprint that would be practical to execute and still feasible to play. Precision wasn't the absolute highest priority, but in order to keep the instrument from leaning sideways, or even falling apart when struck with the mallets, a certain amount of accuracy was required. After several iterations of design, generated in Adobe Illustrator, I reached a layout that would produce the results I was looking for. I will later discuss ways that I would revise this layout if I were to produce another instrument. The creative process is never finished.

Secondly, I had to document and release the plans to this instrument in a format that would allow for accurate recreation or improvement. I wanted to be sure that a follower could feel confident that he or she understood the step-by-step process. The best way to show this is through video. Using this medium, there would be no questions about what steps I took to get the results that I did. Admittedly, I'm not a master craftsman, but I've had training with power tools and am capable of getting the results that I'm looking for with them. The videos allow for the best demonstration of the methods that I used. To disperse the plans and step-by-step videos, I used a website that I created, BjBuller.com, under a heading called "Buller Builds," under which I intend to continue to post new projects.

Acoustical Design Process

In the fall of 2007, I learned the basics of how sound is created, observed, and interpreted in an acoustics course, MUMET 125. Additionally, we studied the way various instruments create sound, and the principles and formulae to measure and predict how any body would produce sound when excited. While designing this pipe marimba, I've had to apply the knowledge learned during my freshman year. Using *The Science of Sound* by Thomas Rossing, also the textbook for MUMET 125, I found the specific formula to find the frequency of sound produced by a vibrating column of air based on the length of the tube (65).

$$f = \frac{v}{2L} \qquad v = \text{speed of sound } (\approx 340.29 \text{ m/s or } 13386 \text{ in/s})$$

This is the chief sound formula that the instrument is based upon. All aspects of the design revolve around the length of the tubes required to produce the desired frequencies.

The obvious ultimate goal of this project is to create a playable musical instrument. I did not want the instrument to simply produce sound in an abstract way, but rather to be accessible to most musicians with any amount of training at all. For this reason, I built the instrument on the existing layout of a traditional keyboard instrument. The notes C, D, E, F, G, A, and B are all on the first, or closer row of tubes, while C#, D#, F#, G#, and A# are all on the second, or farther row of tubes. For clarity, I will call this farther row of tubes the second tier. I chose to use 20 pitches, C-2 through G-3, because it would allow the performer to play a full octave scale in at least half of all existing keys. It also allows for a reasonable treble and bass contrast. The layout allows most amateur musicians to understand how to play the instrument without any prior instruction.

I created a spreadsheet using the resonant tube formula (mentioned earlier) based on a model originally created by Nate True (True). This spreadsheet allowed me to plot every note that I intended to use in my tube array, indicate its frequency, and then calculate the length using the vibrating air column formula from page 4. As I began to cut the lengths of tube from my roll of drainage tube, I assumed that these lengths would be accurate and allow me to simply measure and have my tube lengths pre-tuned to the desired pitches. Unfortunately this was not the case. The actual lengths of the tubes deviated from the expected lengths of tube by an average of 5.65 inches per tube. I will discuss later my hypotheses for this large difference. See Table 1 on page 6 for more data.

Table 1: Tube Length Calculations

	Note	Freq (Hz)	Tube Size (in)	Length (in)	Length (ft)	(in)	Actual Length (in)	Deviation (in)
1	**C-2**	65.41	3.00	100.50	8	4 8/16	94.50	6.00
2	**C#-2**	69.30	3.00	94.76	7	10 12/16	87.50	7.26
3	**D-2**	73.42	3.00	89.34	7	5 5/16	82.25	7.09
4	**D#-2**	77.78	3.00	84.22	7	3/16	75.50	8.72
5	**E-2**	82.41	3.00	79.39	6	7 6/16	72.75	6.64
6	**F-2**	87.31	3.00	74.83	6	2 13/16	67.75	7.08
7	**F#-2**	92.50	3.00	70.53	5	10 8/16	65.00	5.53
8	**G-2**	98.00	3.00	66.47	5	6 7/16	60.50	5.97
9	**G#-2**	103.83	3.00	62.63	5	2 10/16	58.00	4.63
10	**A-2**	110.00	3.00	59.02	4	11	53.00	6.02
11	**A#-2**	116.54	3.00	55.60	4	7 10/16	49.50	6.10
12	**B-2**	123.47	3.00	52.38	4	4 6/16	46.00	6.38
13	**C-3**	130.81	3.00	49.33	4	1 5/16	44.00	5.33
14	**C#-3**	138.59	3.00	46.46	3	10 7/16	42.00	4.46
15	**D-3**	146.83	3.00	43.75	3	7 12/16	39.25	4.50
16	**D#-3**	155.56	3.00	41.19	3	5 3/16	36.25	4.94
17	**E-3**	164.81	3.00	38.78	3	2 12/16	33.75	5.03
18	**F-3**	174.61	3.00	36.50	3	8/16	32.50	4.00
18	**F#-3**	185.00	3.00	34.35	2	10 6/16	31.00	3.35
20	**G-3**	196.00	3.00	32.32	2	8 5/16	28.25	4.07

Average Deviation 5.65

Total tubing (inches)	(feet)	(inches)
1212 5/16	101	5/16

Speed of sound is below:
13386 in/s

Instead of tuning the tubes using theoretical measurements, I tuned the instrument by ear. I did not use an electronic tuner because when I attempted to use one, it was not able to track to the pitch of the tube before the sound dissipated entirely. The tube has a very large transient attack, but very little sustain of the tone at the tuned frequency, and the tuner did not have enough time to capture the sustaining tone before the sound terminated. To overcome this, I simply tuned the instrument by ear. I played notes on a sustaining instrument, specifically a melodica, and whittled down the tube until it reached the pitch played on the melodica. It took some extra time to cut around the tube over and over to trim down the length gradually, but it did yield reasonable results. The instrument is in tune with itself and can play triadic harmonies quite well.

Structural Design Process

In the Vision Statement section, I mentioned that one of the main requirements of this project was to make the project accessible to any builder. I made it my highest goal to keep the entire project under $100 in materials, which ended up being much easier than I thought it might be. Table 2, below, shows the prices for various items that I used, if bought new. It would be completely possible to do this project for less using recycled or repurposed products. All of the products I used are easy to manipulate given a fairly standard set of tools. I simply used a utility knife, power drill, circular saw, and jig saw. None of these tools are difficult to locate in a store, or even borrow for that matter.

The choice of materials was obviously important in the design for both cost reasons and practical reasons. Corrugated drainage tubing was a clear choice because of the price. It had added benefits, as well. Corrugated tubing is very lightweight, easy to cut through with just a utility knife, flexible, and uniform enough to produce accurate pitches. Plywood and 2x4s have similar properties. They are widely available, cheap, easy to manipulate with easy-to-find tools, and simple to assemble.

Table 2: Price List

Item	**Price**
100 ft. roll of 3 in. corrugated tubing	$31
Additional 10 ft. length of tubing	$2
Full sheet of 3/8 in. plywood	$12
4 - 96 in. 2 x 4 boards	$8
Box of 2 1/2 in. screws	$4
Flip-flops	$3
Construction-grade adhesive	$5
Total Price	$65

The design of the pipe marimba was based on the design of any keyboard instrument. There are two tiers of notes, with the sharps and flats on the second tier. In all, 20 different notes fill the set of tubes. This is the equivalent of one octave and an extra interval of a fifth, with all chromatic steps in between. I started by designing some prototypes in Illustrator, and eventually came upon a final design that would work. I needed enough space to fit all 20 chromatic notes on two different tiers, with some space in between so you could strike one note without hitting two simultaneously. The frame also needed some structural reinforcement and stability, so I left some extra room for 2x4 bracing on the bottom of the top plate. See the blueprint on page 15 for a graphical representation of the structure.

I will not go until much detail here about the actual building process, which is explained in great depth in the step-by-step instructional videos, included in this report. I did have some setbacks, though, and had to make many manipulations on the fly. Two design features, in particular, were puzzling until I got some advice. The attachment of the tubes to the frame was the chief obstacle that I encountered. The tubes were too thin to be screwed or nailed to the wood because of the susceptibility to cracking over time from being struck with a mallet. After a couple of different attempts, I used a collar that wraps around the tube and has a diameter that is wider than the hole in the wooden top plate of the marimba. This way, the tube cannot slide downward because the collar is too big to fall through the hole.

The other obstacle, nearly until the end of the project, was what to use as a mallet to strike the tubes. I had entertained the idea of cutting my own paddles out of wood, or even using Ping-Pong paddles. Instead, through the advice of a friend, I used flip-flops. They are flexible so they can form to the shape of the top of the tube, yet strike with enough force to produce a satisfying tone. Their weight enables the instrumentalist to play rather quickly. I later found out that I am not the first one to use flip-flops as mallets. A recent exhibit at the Boston Children's Museum included a similar instrument that used these lightweight mallets (Boston).

Please view the DVD included with this report to see the building process in depth.

Distribution

As a digital media minor, I understand the increasing simplicity and availability of distributing information, peer-to-peer, to almost anywhere in the world at any point in time. Instead of a one-to-many distribution, such as contemporary mass media's example, any basic

Internet user can generate content, put it online, and simply wait for people to find it—providing they are looking of course. From the beginning, it was my goal to put this content online where it can, if people want, be found, used, and edited by anyone for free.

Video, I have found, is the best medium to express an idea. Second to live experience, you can fit the most information into a video. I chose to take advantage of the medium's strengths in order to deliver the directions and methods for this project in a way that was easy to understand. I documented, with a digital camera, every step of my process. After I was done with each step (there are five total steps), I took the raw video and edited it down to the point where a person could follow what I was doing, but wouldn't need to sit through hours of video for each cut that I made. Each video is around five minutes long.

After all of the videos were complete, I posted them online on YouTube.com and embedded them on my own website, BjBuller.com. This allowed me great flexibility for my delivery method. YouTube has been a great video host for millions of people for years. It has a massive pool of users, so it is likely the best way to reach the largest target audience. There are many builders in the online YouTube community, and even many videos of similar pipe marimbas. Most of the other pipe marimbas are being performed, rather than built, though. My video series, so far, is one-of-a-kind of the Web.

Since I also put the videos on BjBuller.com, I could upload other types of downloadable information. For instance, the price list is online, as well as some of the research that I put into the pipe marimba. Most importantly, it allows me to have a nice hub to store all of the information together. The blueprint document is available for free download on the same page as the instructional videos, which keeps users from moving back and forth between sources, like Scribd and YouTube.

In today's remix culture, the Internet is filled with chopped up, dubbed over, mashed up, reversed, and edited files that originated somewhere else. Larry Lessig, the man behind the Creative Commons License, makes claims that we are criminalizing creativity because of the stipulations we put on the use of our ideas. His solution, the one I have adopted, is to release information and ideas under a different type of copyright, known as the Creative Commons. Without going into too much detail, because it is not the focus of this report, Creative Commons allows a user to take content from the internet and reuse it, with attribution given to the original creator, for other purposes. I posted my content under the Creative Commons License in order to allow others to use my ideas, but also allow them to remix my videos or edit my portable documents and then rerelease them with a similar license. This way, an idea that was given to me (in this case, a pipe marimba) can be documented in a series of how-to videos, then can later be built and transformed into a new idea, that could later also be transformed in turn. Using Lessig's model, the creative possibilities are endless.

Analysis and Conclusions

As with all creative endeavors, there were many places where my results were unexpected or even downright disappointing. Through building this instrument, I learned a great deal about the creative process. I learned that many revisions are often necessary since the first iteration is typically the worst. I learned that advice, which is sometimes hard to find, is always useful, even if you decide not to follow it completely. I learned that there are many ways to achieve a certain goal, but it can be difficult to decide on one, particularly when you will have to start from scratch if the results do not turn out how you wanted, or if you invest money into your top choice.

I had many frustrations during this project that allowed me to learn these lessons. In particular, the materials I used create large hurdles, and even some perplexities that still have me drawing hypothesis. To begin with, I have mentioned in the acoustical design process section of this report that the actual lengths of tubing did not match the theoretical lengths with respect to a given pitch. In fact, the tubes were an average of 5.65 inches shorter than the expected lengths. I have a few conjectures on this topic.

First, the tubes are not straight. Rather, they are arc-shaped. When I measured using a standard measuring tape, I took the measurement of the inside of the arc. The outside, I am sure, has a markedly longer length for each individual tube. I would estimate that each length would be at least 5 inches longer, just by measuring from a different point. The question remains, however, what is the effective length of the tube, regardless of the measuring point or degree of curve in the arc? In my estimation, the effective length of the tube would be measured to the center of the arc. This would be the point where, acoustically, the sound pressure level would likely find to reach zero, thus creating the acting wavelength that determines the practical tube length measurement.

Secondly, because of the large diameter of the tubes, the pressure level could reach zero in a shorter distance than the end correction (.61 x radius) initially states (Rossing, 66). End correction is meant to take into account the fact that it takes a distance that is slightly longer than the physical tube length for the wavelength to rebound and return through the tube. This might be shorter than anticipated, because the large mouth of the tube would be able to dissipate the sound pressure much more quickly than in a narrower tube. I have found no evidence that states that the end correction functions this way. In fact, my theory would present an exponential function of the radius to the length, rather than a linear function as presented in the Rossing text.

This will be part of my ongoing research with the pipe marimba as I continue to use it in the future. The lengths and data are all shown in Table 1, on page 6.

There were other design flaws besides simply the inconsistent measurements. Corrugated tubing provided a structural challenges as well as an acoustical one. It was difficult to get the tubes to stay still in the frame. One can see in the fourth instructional video in the series that I did not firmly attach the tubes to the wooden frame, but instead let them rest on a collar on the top plate. This was poor for two reasons.

First, the tubes did not stay straight in their respective holes. They were free to rotate, which was not an immediate problem, but it became a problem when the tubes stopped standing up straight. This was an issue because it was more difficult to strike the tubes when they were sitting at cockeyed angles, not straight up and down, which would have been ideal. This was also an issue with the sound of the tubes when struck. The tubes rattled in the holes when hit with the mallets, which was undesirable. If I can find a way to attach the tubes to the frame, I imagine that the sound will be much less colored by the rattling of the plastic against wood. I have tried simply holding the tube in place with my hand while striking it with a mallet, and the results were improved greatly. Hopefully, in a future design revision, I can find a better method of attachment than in the current design. Having a uniform angle and space for each tube would improve both the playability and the sound purity of the instrument.

I would also take the second tier of tubes and move them an extra two inches farther away from the first tier of tubes. This would allow a performer to hit the first tier much more easily without fear of hitting the second tier accidentally. I may also separate each tube along the x-axis even wider as well. The distance between the tubes is enough currently, but more would be very beneficial if playing at high speeds.

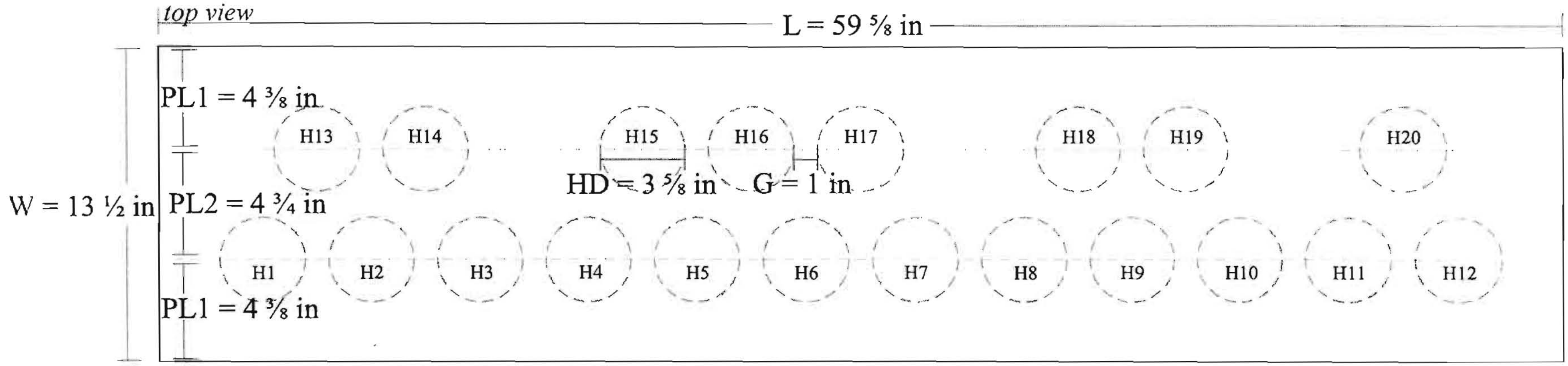
Lastly, the future of my instrument may be in the electronic realm. Obviously, I have fulfilled the initial goals of this instrument. The instrument is built, and costs considerably less than the restraints I placed upon the project. The plans have been placed in a location that is readily accessible to anyone who is looking for such plans. I have presented this instrument before an audience of peers in the music technology department, as well as members of the staff of the department and an Auralex acoustics company representative. I have even recorded sound from the instrument, which is exactly the direction I intend to pursue next.

The sonic capabilities of this instrument are limited only by imagination in the electronic domain. I have started experimenting with the recorded sound of the instrument, and have found some interesting and unique sounds that could be formed into an entire electronic composition. Particularly, delay effects, resonant and spectral effects, and granular effects sound fantastic. Since the instrument is percussive, delay effects can create complex rhythms that are impossible with only two hands playing the instrument. Resonant and spectral effects are interesting because they heighten the effect of the resonant sound the tubes produce already. Granular effects are unique because they allow the short attack to ring out for much longer periods of time, which becomes nearly impossible to relate back to the initial envelope of the instrument. The combined effect of these sounds could build an electronic composition in the near future.

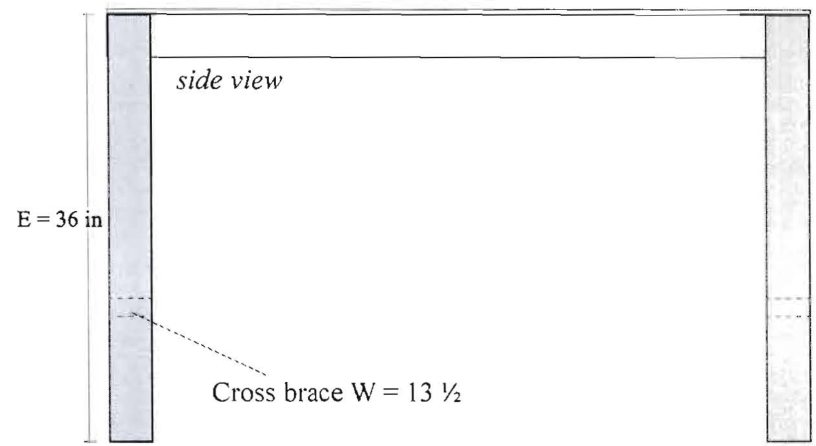
The lessons I've learned from this project have been great. Without a particular set of rules to follow constructed by an professor, I was able to create my own design requirements, and do my best to fulfill them. This will become very important in a matter of weeks, when I enter the job market and no longer have strict rules to follow, but instead will be judged based on how well I am able to reach specific goals. With the framework to set my own goals and find my own alternatives, I now have the ability to chart my own path through a project.

Pipe Marimba Blueprint

Brandon Buller



Title	*Measurement (in)*	*Title*	*Measurement (in)*
W (Width)	13 1/2	H7	32 1/8
L (Length)	59 5/8	H8	36 3/4
G (Gap)	1	H9	41 3/8
PL1 (Pipe Line 1)	4 3/8	H10	46
PL2 (Pipe Line 2)	4 3/4	H11	50 5/8
HD (Hole Diameter)	3 5/8	H12	55 1/4
E (Leg)	36	H13	6 11/16
B (Cross Brace)	10 1/2	H14	11 5/16
H1 (Hole 1 Center Point)	4 3/8	H15	20 9/16
H2	9	H16	25 3/16
H3	13 5/8	H17	29 13/16
H4	18 1/4	H18	39 1/16
H5	22 7/8	H19	43 11/16
H6	27 1/2	H20	52 15/16



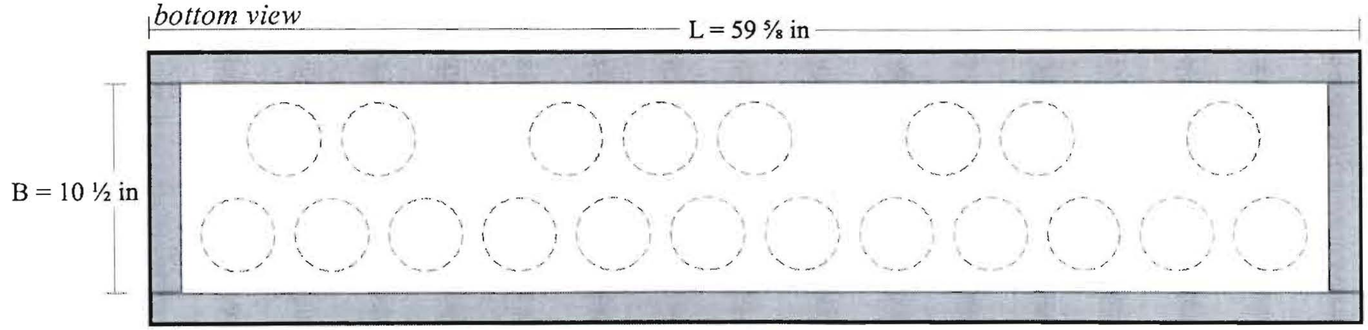


Figure 1: Pipe Marimba Blueprint

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